Complete Summary

GUIDELINE TITLE

Clinical stress testing in the pediatric age group. A statement from the American Heart Association Council on Cardiovascular Disease in the Young, Committee on Atherosclerosis, Hypertension, and Obesity in Youth.

BIBLIOGRAPHIC SOURCE(S)

Paridon SM, Alpert BS, Boas SR, Cabrera ME, Caldarera LL, Daniels SR, Kimball TR, Knilans TK, Nixon PA, Rhodes J, Yetman AT, American Heart Association Council on Cardiovascular Disease in the Young. Clinical stress testing in the pediatric age group: a statement from the American Heart Association Council on Cardiovascular Disease in the Young, Committee on Atherosclerosis, Hypertension, and Obesity in Youth. Circulation 2006 Apr 18;113(15):1905-20. [75 references] PubMed

GUIDELINE STATUS

This is the current release of the guideline.

COMPLETE SUMMARY CONTENT

SCOPE

DISEASE/CONDITION(S)

Diseases and conditions requiring clinical stress testing for evaluation, including:

- Congenital heart disease
- Acquired heart disease
- Pulmonary disorders
- Gastrointestinal disorders
- Metabolic disorders

- Other organ system disorders

GUIDELINE CATEGORY

Evaluation
Risk Assessment

CLINICAL SPECIALTY

Cardiology
Pediatrics
Physical Medicine and Rehabilitation
Pulmonary Medicine
Sports Medicine

INTENDED USERS

Allied Health Personnel
Health Care Providers
Nurses
Physicians

GUIDELINE OBJECTIVE(S)

- To provide guidance on testing protocols, equipment needs, and appropriate use of pharmacological agents for pediatric patients undergoing stress testing
- To supplement and update the previous American Heart Association publications on exercise testing in children

TARGET POPULATION

Children and adolescents undergoing stress testing

INTERVENTIONS AND PRACTICES CONSIDERED

1. Ensuring adequate physical environment
2. Ensuring appropriate laboratory equipment:
    - Treadmill ergometers
    - Cycle ergometers
    - Emergency equipment
    - Measurement devices
3. Pretest procedures
    - Informed consent
    - Diet
    - Dress
    - Placement of electrocardiogram (ECG) leads
    - Choice of blood pressure cuff
    - Placement of breathing masks
    - Pretest practice
4. Ensuring appropriate laboratory staffing
5. Monitoring

    - ECG recording
    - Blood pressure measurement
    - Pulse oximetry
    - Metabolic measurements
    - Echocardiography
    - Nuclear myocardial blood flow imaging
    - Spirometry
6. Emergency interventions
    - Defibrillator
    - Oxygen
    - Emergency drugs
7. Multistage incremental stress protocols
    - Treadmill protocols (Bruce, Balke)
    - Cycle protocols (James, McMaster, Strong)
8. Progressive incremental cycle ergometer protocols
9. Constant-work-rate protocols
10. Alternative protocols
    - Exercise-induced bronchospasm provocation
    - Six-minute walk test
    - Pharmacologic stress protocols (dobutamine, isoproterenol, adenosine, dipyridamole, esomolol, aminophylline)

MAJOR OUTCOMES CONSIDERED

- Blood pressure
- Heart rate
- Heart rhythm
- Oxygen uptake
- Oxyhemoglobin saturation
- Ventilatory and pulmonary gas exchange responses

METHODOLOGY

METHODS USED TO COLLECT/SELECT EVIDENCE

Searches of Electronic Databases

DESCRIPTION OF METHODS USED TO COLLECT/SELECT THE EVIDENCE

Not stated

NUMBER OF SOURCE DOCUMENTS

Not stated

METHODS USED TO ASSESS THE QUALITY AND STRENGTH OF THE EVIDENCE

Not stated

RATING SCHEME FOR THE STRENGTH OF THE EVIDENCE

Not applicable

METHODS USED TO ANALYZE THE EVIDENCE

Review

DESCRIPTION OF THE METHODS USED TO ANALYZE THE EVIDENCE

Not stated

METHODS USED TO FORMULATE THE RECOMMENDATIONS

Not stated

RATING SCHEME FOR THE STRENGTH OF THE RECOMMENDATIONS

Not applicable

COST ANALYSIS

A formal cost analysis was not performed and published cost analyses were not reviewed.

METHOD OF GUIDELINE VALIDATION

External Peer Review
Internal Peer Review

DESCRIPTION OF METHOD OF GUIDELINE VALIDATION

All American Heart Association (AHA) Scientific Statements undergo blinded peer review and are reviewed and approved by the AHA Science Advisory and Coordinating Committee (SACC), the highest scientific body of the AHA.

Expert peer review of AHA Scientific Statements is conducted at the AHA National Center.

This statement was approved by the American Heart Association Science Advisory and Coordinating Committee on December 30, 2005.

RECOMMENDATIONS

MAJOR RECOMMENDATIONS

I. **Physical Environment**

The exercise physiology laboratory should provide an ideal environment for vigorous exercise. This requires adequate space and climate control. The laboratory must be large enough to accommodate the treadmill and/or cycle ergometer, electrocardiograph (ECG) machine, metabolic cart, and patient examination table and still be able to provide sufficient room on both sides of the ergometer for emergency equipment should it be needed. Approximately 500 sq ft is usually adequate. With the use of multiple ergometers and testing stations, the space allocated must increase proportionally. It is also preferable to have a space at the back of the room for a parent to sit during the test. Temperature should be maintained in the range of 20 degrees C (68 degrees F) to 24 degrees C (75 degrees F) with a relative humidity of between 50% and 60%. Lighting throughout the laboratory must be adequate to allow complete viewing of the patient and equipment.

Laboratory Equipment

The pediatric exercise physiology laboratory must be equipped with age- and size-appropriate ergometers, emergency equipment, and measurement devices (such as appropriately sized blood pressure cuffs, pediatric mouthpieces, and pediatric face masks). A treadmill should have appropriate-height handrails (both sides and front). Cycle ergometers have adjustable seat height so that the child can reach the pedals and have an ~10 degree to 15 degree angle of flexion at the knee when the leg is extended. It may be necessary to use blocks to increase the height of the pedals for smaller children, although it is always better to use ergometers with adjustable leg cranks and handlebars. A fully stocked emergency resuscitation cart should be present in the laboratory during testing. Additional safety equipment such as oxygen and suction should be present in the laboratory during all testing.

Pretest Procedures

Before the arrival of the patient for testing, it is helpful to provide the patient and family with written information about the test as well as pretest guidelines with regard to diet and clothing. Patients do not have to be fasting for a standard cardiopulmonary exercise test. However, they are cautioned not to consume caffeine on the day of the test (including caffeinated soda) or eat a heavy meal within 2 to 3 hours of the test. Patients are instructed to wear or bring comfortable exercise clothing, preferably shorts, T-shirt, and athletic shoes. The pretest information can be mailed to the family with an appointment reminder and instructions to come to the laboratory well rested. (See Figure 1 [a sample of the form used to explain an exercise test to parents and patients] in the original guideline document).

When the patient arrives at the exercise laboratory for testing, the testing procedure should be explained again to the child and the parent in terms that they can both understand. For standard cardiopulmonary exercise testing, children should be reassured that the test does not hurt and is usually even fun. The child and parent should then be given the opportunity to have all questions about the test answered. Written informed consent is often obtained before the exercise test, and the patient should be told that he or she can terminate the test at any time even though he or she will be encouraged to continue to volitional fatigue and that the time he or she will be exercising is usually 10 to 15 minutes. The use and type of each form will vary according to the individual institution's requirements but should meet the standards of meaningful informed consent. Verbal assent should be obtained from the child if over the age of 7 or 8 years.

In preparation for the test, the patient is fitted with 10 electrodes so that a continuous 12-lead ECG tracing can be obtained during testing. The skin should be cleansed with alcohol, with care taken to assure small children that this does not indicate they will be getting an injection because many children associate alcohol swabs with needles. The skin should be abraded gently with ECG skin preparation paper or rough gauze. Some clinicians believe that commercially available "drills" and electrode placement guns are useful. Electrode placement should be in a modified version of the Mason-Likar placement, with the arm leads at the lateral and superior corners of the sternum and the leg electrodes near the right and left inferior rib margins between the midclavicular and anterior axillary lines. In patients undergoing exercise echocardiography, the position of the electrodes may be modified slightly to permit access to adequate echocardiographic windows. Likewise, lead position may need to be modified to accommodate breast tissue in adolescent females, and chest hair removal may be needed in adolescent males. The lead wires should then be attached to the electrodes and the patient cable and lead-wire box fitted snugly around the child's waist. A stress test vest or net shirt helps to keep the electrodes and wires firmly in place when the child is exercising. Appropriately sized blood pressure cuff and pulse oximeter sensor (if used) should be placed at this time.

Before exercise, the patient should be given the opportunity to familiarize himself or herself with the breathing apparatus (airtight mouthpiece or mask) if a metabolic or pulmonary stress test is to be administered. Breathing with a face mask is more natural and prevents coughing and drying of the airways. At the onset of exercise, patients should be given a warm-up period consisting of low or no workload to acclimate the patient and to collect baseline data. Before the exercise test, the staff should also familiarize themselves with the patient's medical history so that they may anticipate abnormalities that may be encountered during the test and identify the clinical questions that need to be addressed by the test.

Laboratory Staffing

A physician trained in exercise testing and exercise physiology should have the primary oversight responsibility for the laboratory and testing.

The director of the exercise laboratory may be either a physician responsible for the laboratory or a nonphysician trained in pediatric exercise physiology and testing. Ideally, a nonphysician director should have training in exercise physiology at least at a master's degree level. The director's responsibilities include ensuring that (1) all laboratory personnel are thoroughly trained in testing and emergency procedures; (2) all equipment is working properly and is properly maintained; (3) appropriate testing procedures are used on the basis of the patient's diagnosis and the information desired from the exercise test; and (4) results of the stress testing are conveyed in a reliable and timely manner to both the referring physician and family.

An exercise test may be conducted by laboratory personnel who have been properly screened, are familiar with pediatric pathophysiological responses to exercise testing, and have expertise in pediatric emergency procedures. At least 2 properly trained persons are needed to perform an exercise test. At least one of these should be trained in pediatric advanced life support, and standard pediatric cardiopulmonary resuscitative equipment should be immediately available during all testing.

For all diagnostic testing, a physician should be immediately available. Physicians may need to be present and/or supervise testing depending on the risk to the patient, the expertise of the laboratory personnel, and the complexity of the clinical question being addressed. Most low-risk testing may be done without direct in-laboratory physician supervision. Higher-risk studies should have direct supervision. Individual patient risks should always be taken into consideration when the decision is made about physician supervision.

II. **Informed Consent**

It is recognized that different institutions have different approaches to the process of informing patients and their families about medical procedures. There may be differences in the law from state to state. Nevertheless, it is vitally important that young patients and their parents know what to expect when they are involved in exercise testing. This information about what will be done, why the test is needed, and which aspects of the test may result in discomfort or risk is necessary to obtain the best test results. For some patients, the risk of exercise may be higher. For these patients, a careful explanation of the risks involved and the precautions taken to avoid excess risk or to deal with expected or unexpected medical complications is important. It may also be helpful to document that this exchange of information has occurred, either in the patient's medical record or with an informed consent document. The personnel of the laboratory should respect the right of the family to be informed about the test. A discussion of how or why the test might be terminated, including at the request of the patient, should also occur before the test. The patient's right to terminate the test should be respected.

III. **III. Equipment Requirements**

A pediatric exercise laboratory should be able to perform a spectrum of testing on children with a wide variety of medical conditions. This will usually require at least a treadmill and a cycle ergometer. In addition, equipment to measure physiological responses to exercise such as heart rate, blood pressure, oxygen saturation, and expired gases is usually required. Equipment for more specialized testing such as pharmacological stress testing and echocardiographic imaging is also needed in certain circumstances.

Treadmills and Cycle Ergometers

Any patient who lacks experience walking on a treadmill should be tested only after having practiced and gained confidence in walking, running, and stepping on and off the treadmill. However, it is recommended to judge this on a case-by-case basis with consideration of the child's size, ability, and coordination.

Cycle ergometers typically are less expensive and less noisy and require less space than treadmills. Measurements of gas exchange and blood pressure, as well as ECG and echocardiography measurements, are easier to perform on subjects exercising on a cycle ergometer than on a treadmill. Thus, in most clinical circumstances, the cycle ergometer provides more reliable physiological measurements during exercise. However, some children, especially those 6 years and younger, may have difficulty keeping a steady cadence when pedaling, even when the cycle ergometer is adjusted to accommodate their size.

Refer to the original guideline document for additional discussion concerning treadmills and ergometers.

The guideline developer's recommendation is that exercise physiology laboratories that serve a pediatric population have available modern ergometers (treadmills and stationary bicycles) possessing features that facilitate the testing of children and the interpretation of their test results.

1. *Electrophysiological Equipment*

    ECG recording is critical to stress testing for 3 purposes (1) accurate assessment of heart rate to evaluate exercise effort and end point of the test; (2) diagnosis and evaluation of arrhythmia; and (3) assessment of conduction abnormalities and ST-segment and T-wave changes consistent with myocardial ischemia and QT interval. ECG recording leads should be placed after proper skin preparation to afford good-quality recording throughout the test. A 12-lead ECG should be recorded before the test. It is sometimes helpful to obtain these studies in supine and upright positions with and without hyperventilation to identify changes in T-wave morphology.

    ECG recording equipment used for exercise testing should have a real-time display screen and a "writer" or printer to create copies of real-time or review ECGs. The display screen should be of adequate size so that it can be seen easily by the testing personnel during the study. It should display at least 3 leads of ECG in real time and ideally have a numeric display of instantaneous heart rate. Instantaneous "superimposition" scanning of median ECG complexes from selected leads can improve the sensitivity and rapidity of real-time detection of ST-segment changes during exercise. Analog ECG recording is acceptable, but digital acquisition has become more common to facilitate superimposition scanning and electronic storage. Digital recording should have a minimum sampling frequency of 1 megahertz (mHz), but many systems improve the quality of recording with a frequency of 4 mHz. Configurable high- and low-pass filters, as well as a "line" or "notch" filter, can substantially improve the quality of ECG recording in a laboratory with numerous other electric devices. The writer should be capable of printing immediate copies of real-time ECG and continuous ECG rhythm strips. It is also convenient if it can print an ECG recorded previously during the study for review. Printing of median ECG complexes in the report at each stage can improve the efficiency of analysis by a subsequent interpreter. A computer-based recording system, in addition to facilitating report generation, can also provide "full-disclosure" review of ECG waveforms during a study. This allows review of arrhythmia or morphology changes that may have occurred when paper ECG recordings were not being created.

2. *Blood Pressure Measurement*

Blood pressure is an important variable to evaluate during exercise testing. In some cases, such as in evaluation of coarctation of the aorta or aortic stenosis, it may be one of the primary variables of interest.

It is generally recommended that blood pressure be measured (1) at rest before beginning the exercise test, (2) frequently during the exercise test to evaluate blood pressure elevation or to detect impending hypotension, and (3) during the recovery period to ensure that systolic blood pressure returns to near baseline values. In most tests, measurements every 3 minutes during exercise and recovery are adequate. However, more frequent measurements may be required if symptoms of hypotension are present.

To use blood pressure data with exercise testing, it is important to have accurate and reliable measurements. Refer to the original guideline document for additional discussion of the accuracy and reliability of various blood pressure measurement devices.

Whichever indirect method is chosen, the cuff size must be appropriate for the arm size of the patient. This means that pediatric exercise testing laboratories must have a variety of cuff sizes available. The cuff size selection should be based on the circumference of the arm. The cuff should completely encircle the arm. The width of the cuff bladder should be at least 40% of the arm circumference at the midpoint.

The person measuring blood pressure by auscultation is the most important factor in the acquisition of accurate and reliable blood pressure measurements. This individual must be properly trained in the methods of blood pressure determination and interpretation. The person must have good vision, hearing, and coordination between the eye, hand, and ear (for auscultatory measurements). Those who are measuring blood pressure should also undergo periodic retraining with evaluation of their technique.

3. *Pulse Oximetry*

Oxyhemoglobin saturation is typically measured during exercise with a pulse oximeter. The 2 most commonly used types of oximeters measure the saturation at either the fingertip or ear lobe. Both types of probes are usually reliable if a good pulse is detected and the corresponding heart rate from the probe closely matches the heart rate obtained from the ECG equipment. In the absence of an adequate signal, the measurement is unreliable and will frequently underestimate the actual arterial oxygen saturation. Bright overhead lighting and darker skin pigmentation may also hinder detection of an adequate signal. In the presence of marked hypoxemia, pulse oximeters will also become unreliable and underestimate arterial saturation. Ensuring adequate surface contact and perfusion will improve the pulse oximeter reliability. If an ear probe is used, any ear jewelry that may interfere with the seating of the probe should be removed. Gently rubbing the lobe to improve local perfusion may also be helpful. When a finger probe is used, it is important to discourage the patient from tightly gripping the support bars or handlebars of the ergometer.

4. *Metabolic Cart*

The determination of the ventilatory and pulmonary gas exchange responses to exercise requires measurement of either volume or airflow and the fractional concentrations of oxygen (FEO_2) and carbon dioxide ($FECO_2$) in the expired air. From measurements of these 3 signals, valuable exercise variables and parameters can be determined and/or calculated. Among them are minute ventilation (VE), respiratory rate, and tidal volume (VT), as well as oxygen uptake (VO_2) and carbon dioxide output (VCO_2). Other useful exercise variables that can be derived from these responses include ventilatory equivalent for oxygen (VE/VO_2) and carbon dioxide (VE/VCO_2), the end-tidal partial pressure of carbon dioxide ($PETCO_2$), and respiratory exchange ratio. Two parameters useful to evaluate functional capacity or endurance, namely, maximal oxygen uptake (VO_2max) and ventilatory anaerobic threshold (VAT), can be estimated from the time profile of the aforementioned variables.

Regardless of whether a mixing chamber or a breath-by-breath system is used, care must be taken to ensure that the mouthpiece or mask used to collect expired air in children fits properly and that there are no air leaks. In smaller children and those patients with severe restrictive lung disease, care should be taken to ensure that the dead space of the system is not excessive. Closely fitting masks with a sealant gel may be more suitable for younger children who do not easily tolerate a mouthpiece and nose clip. When properly sealed and airtight, masks provide a more comfortable approach to collecting expired air in children and adolescents.

Common criteria to determine whether the child gave a maximal effort are as follows: (1) a respiratory exchange ratio (VCO_2/VO_2) >1.1; (2) a peak heart rate approaching 200 beats per minute (may not be attained in children with chronotropic or other limitations to exercise); and (3) subjective opinion of experienced testers.

Details for calculating oxygen uptake at maximal exercise (VO_2max), the VO_2 at which the VAT occurs, the oxygen pulse (the amount of oxygen consumed per heartbeat), the VO_2-work relationship, and ventilatory efficiency are included in the original guideline document.

Noninvasive Measurement of Cardiac Output Using the Metabolic Cart

Various techniques have been used for noninvasive evaluation of cardiac output during exercise. Historically, the 3 most common techniques have included the CO_2 rebreathing method, acetylene rebreathing method, and use of continuous-wave Doppler echocardiography. All 3 techniques have their shortcomings and thus have largely been limited to use in the research setting. Recent software developments allow for a single-breath maneuver to be performed during exercise that may allow for assessment of cardiac output near peak exercise. The technique requires inhalation of an inert gas (acetylene) that is soluble in tissue and blood. The rate of alveolar absorption is proportional to the pulmonary capillary blood flow. The rate of absorption is determined by repeated measurements of the exhaled concentration of the gas obtained from a controlled single exhalation maneuver. The maneuvers required for both the single breath and rebreathing methods are often difficult for small children, especially at higher minute ventilation. This can often limit the usefulness of these techniques in the pediatric population.

5. *Echocardiography Equipment*

Accurate interpretation of wall motion abnormalities may be optimized by the use of a high-quality ultrasound system equipped with digital archiving and split- or quad-screen displays. This allows for a side-by-side comparison of resting and stress images. In pediatrics, systems with high frame rates, providing better temporal resolution, are optimal because the heart rate will be quite rapid during administration of stress. Additional equipment should include an ECG system equipped with a stress package enabling display and analysis of ST-segment trends, blood pressure monitor, and oximeter. If a pharmacological agent is to be employed for stressing or if contrast agents will be administered, intravenous line equipment is necessary.

6. *Nuclear Myocardial Blood Flow Imaging*

Most maximal exercise protocols are acceptable for use with myocardial perfusion imaging (see the section on exercise protocols below). The only additional equipment requirement during an exercise test is the placement of a peripheral intravenous catheter in a nonexercising extremity. Nuclear myocardial blood flow imaging is frequently combined with pharmacological stress testing. This is especially true for younger patients or when imaging is combined with stress echocardiographic imaging. Specific additional equipment requirements for pharmacological stress testing will be discussed in the protocol section.

7. *Spirometry Equipment*

Spirometry is one of the more commonly performed pulmonary function tests. It provides a flow-volume loop and can assess the degree of airflow obstruction within the airways. Use of spirometry in conjunction with stress tests has become more common. This technique should be performed with the use of equipment and techniques that meet standards such as those developed by the American Thoracic Society. Careful calibration, timing of the study, relationship of medication used at the time of the study, understanding of the correct spirometric technique, and maintaining the equipment are all essential components to achieve meaningful results. Although many of the commercially available spirometry systems provide computer algorithms for determining the acceptability of the patient's technique and interpretation of the study, the individual technician should have sufficient training in identifying the quality of the study and troubleshooting an individual test. Although training courses that are approved by the National Institute for Occupational Safety and Health exist, no approved courses exist for pediatric spirometry. Quality control via consultation with a trained pediatric pulmonary function technician or pediatric pulmonologist should help to optimize the use of spirometry.

8. *Safety Equipment*

In general, exercise testing is safe for children, even for children whose diagnoses place them in a high-risk group. Nevertheless, it is essential that the exercise physiology laboratory be supplied with all the necessary equipment and drugs required to manage any emergency. A defibrillator must be present, tested periodically, and in working condition. Exercise testing personnel should be familiar with the circumstances that call for use of the defibrillator and the protocol to follow in case of an emergency. Oxygen should also be available in the exercise physiology laboratory, either in tanks or built in. In addition, a wall-mounted or portable suction system should be present. Emergency drugs should also be on hand and should be checked regularly to ensure that they are not outdated.

IV. **Indications and Contraindications for Stress Testing**

The indications for stress testing in the pediatric age group are broad and have as a general goal the evaluation of exercise performance and the mechanisms that limit performance in the individual child or adolescent. In any individual test, the questions that need answers may vary on the basis of the child's clinical issues. Table 1 summarizes some of the more common indications for exercise testing in children. It is not inclusive, and others may occur for an individual patient.

TABLE 1. Common Reasons for Pediatric Stress Testing

1.	Evaluate specific signs or symptoms that are induced or aggravated by exercise
2.	Assess or identify abnormal responses to exercise in children with cardiac, pulmonary, or other organ disorders, including the

presence of myocardial ischemia and arrhythmias 3. Assess efficacy of specific medical or surgical treatments 4. Assess functional capacity for recreational, athletic, and vocational activities 5. Evaluate prognosis, including both baseline and serial testing measurements 6. Establish baseline data for institution of cardiac, pulmonary, or musculoskeletal rehabilitation

The benefit of testing in a controlled environment with medical supervision before allowing a child unrestricted activity is often thought to outweigh any procedure-related risks. Certain precautions, however, must be taken to ensure that the procedure is conducted in as safe an environment as possible and that all risks are minimized. It is useful to distinguish between patients at low risk for adverse events and patients at higher risk for adverse events. A physician should be on standby in case of unforeseen complications arising during a low-risk test, and a physician should be present during testing when the test is considered higher risk. Data on current practice for testing of lower- and higher-risk patients are provided in Table 2 and are discussed later in this statement.

TABLE 2. Relative Risks for Stress Testing

Lower Risk	Higher Risk
Symptoms during exercise in an otherwise healthy child who has a normal CVS exam and ECG Exercise-induced bronchospasm studies in the absence of severe resting airways obstruction Asymptomatic patients undergoing evaluation for possible long-QTc syndrome Asymptomatic ventricular ectopy in patients with structurally normal hearts Patients with unrepaired or residual congenital cardiac lesions who are asymptomatic at rest, including 1. Left to right shunts (ASD, VSD, PDA, PAPVR) 2. Obstructive right heart lesions without severe resting obstruction (TS, PS, ToF) 3. Obstructive left heart	Patients with pulmonary hypertension Patients with documented long-QTc syndrome Patients with dilated/restrictive cardiomyopathy with CHF or arrhythmia Patients with a history of a hemodynamically unstable arrhythmia Patients with hypertrophic cardiomyopathy who have 1. Symptoms 2. Greater than mild LVOTO 3. Documented arrhythmia Patients with greater than moderate airways obstruction on baseline pulmonary function tests Patients with Marfan syndrome and activity-related chest pain in whom a noncardiac cause of chest pain is

Lower Risk	Higher Risk
lesions without severe resting obstruction (cor triatriatum, MS, AS, CoA) 4. Regurgitant lesions regardless of severity Routine follow-up of asymptomatic patients at risk for myocardial ischemia, including 1. Kawasaki disease without giant aneurysms or known coronary stenosis 2. After repair of anomalous LCA 3. After arterial switch procedure Routine monitoring in cardiac transplant patients not currently experiencing rejection Patients with palliated cardiac lesions without uncompensated CHF, arrhythmia, or extreme cyanosis Patients with a history of hemodynamically stable SVT Patients with stable dilated cardiomyopathy without uncompensated CHF or documented arrhythmia	suspected Patients suspected to have myocardial ischemia with exertion Routine testing of patients with Marfan syndrome Unexplained syncope with exercise

CVS indicates cardiovascular system; ASD, atrial septal defect; VSD, ventricular septal defect; PDA, patent ductus arteriosus; PAPVR, partial anomalous pulmonary venous return; TS, tricuspid stenosis; PS, pulmonary stenosis; ToF, tetralogy of Fallot; MS, mitral stenosis; AS, aortic stenosis; CoA, coarctation of aorta; LCA, left coronary artery; SVT, supraventricular tachycardia; CHF, congestive heart failure; and LVOTO, left ventricular outflow tract obstruction.

Indications for Exercise Testing Termination

Cardiopulmonary stress testing is often performed to elicit symptoms and to assess cardiac and pulmonary reserves. It is thus desirable to achieve a maximal study in most instances, and care must be taken not to terminate a test too quickly. Three general indications to terminate an exercise test exist: (1) when diagnostic findings have been established and further testing would not yield any additional information; (2) when monitoring equipment fails;

and (3) when signs or symptoms indicate that further testing may compromise the patient's well-being. An attempt should be made to identify quickly the source of the patient's symptoms before termination of the test so that a test is not terminated prematurely. For example, dizziness during exercise may indicate reduced cardiac output, but if a patient's blood pressure is rising appropriately, and there is a normal heart rhythm with a normal rise in heart rate and oxygen pulse, the dizziness is not likely due to inappropriately low cardiac output but rather another cause. Provided that the dizziness is not severe, ongoing exercise may help to clarify the origin. Cardiac and pulmonary parameters should be monitored closely. Clinical judgment should always be used, and test termination is usually indicated if the following occur:

1. Decrease in ventricular rate with increasing workload associated with extreme fatigue, dizziness, or other symptoms suggestive of insufficient cardiac output
2. Failure of heart rate to increase with exercise, and extreme fatigue, dizziness, or other symptoms suggestive of insufficient cardiac output
3. Progressive fall in systolic blood pressure with increasing workload
4. Severe hypertension, >250 mm Hg systolic or 125 mm Hg diastolic, or blood pressures higher than can be measured by the laboratory equipment
5. Dyspnea that the patient finds intolerable
6. Symptomatic tachycardia that the patient finds intolerable
7. Progressive fall in oxygen saturation to <90% or a 10-point drop from resting saturation in a patient who is symptomatic
8. Presence of ≥3 mm flat or downward sloping ST-segment depression
9. Increasing ventricular ectopy with increasing workload, including a >3-beat run
10. Patient requests termination of the study

In all cases, a decision to terminate a stress test should be based on the totality of the available data rather than rigid guidelines.

V. **Protocols**

The protocol selected for exercise testing will depend on the purpose of the test and the characteristics of the patient. Nevertheless, the main criterion to guarantee obtaining a maximum oxygen uptake and good reproducibility of exercise parameters (e.g., ventilatory anaerobic threshold) with a particular exercise protocol on a particular individual is that the exercise protocol should be designed to have the subject reach his or her limit of tolerance in 10 ± 2 minutes.

In principle, many distinct protocols can be implemented and used on either a treadmill or a cycle ergometer. However, to facilitate comparisons with established normative values, standard exercise protocols have been developed that are suitable for most clinical and research applications. The most commonly used protocols fall into one of the following 3 categories: (1) multistage incremental (every 2 or 3 minutes, with a "pseudo" steady state at each stage); (2) progressive incremental (every minute) or continuously increasing (ramp); (3) constant work rate (5 to 10 minutes). In all cases, the exercise protocol is typically preceded by baseline (3 minutes) and warm-up (3 minutes) measurements as well as followed by recovery measurements (5 to 10 minutes).

Multistage Incremental Protocols

Treadmill Protocols

Bruce Protocol

The Bruce protocol was designed originally for diagnosing coronary artery disease in adults, but it has great popularity among pediatric cardiologists. One of the major advantages of using this protocol is that it can be used on subjects of all ages, and thus it can provide comparative exercise data using the same protocol as a child grows. Other advantages are that exercise responses to submaximal work rates can be measured (e.g., VO_2 and cardiac output) and that VO_2max can be estimated from determination of endurance time (r = 0.88). However, the Bruce protocol has some practical disadvantages. For younger or more limited children, the work increments between successive stages may be too great, resulting in the tendency for subjects to quit during the first minute of a new 3-minute stage. For subjects who are well trained, the first 4 stages of the Bruce protocol are too slow, leading to boredom. In addition, the most appropriate running speeds for these young athletes occur at very high elevations (>18%). The 3-minute stages are too long and thus boring for young subjects. In general, regardless of degree of fitness of the individual, most exercise is performed at relatively steep grades when the Bruce protocol is used, which encourages subjects to hold onto the handrails, thereby affecting the oxygen cost of exercise significantly. In addition, the large increases in speed and grade may limit the ability to accurately measure submaximal metabolic data such as the anaerobic threshold.

Balke Protocol

The Balke protocol involves increases in slope while the treadmill speed is kept constant (3.5 mph). As in the case of the Bruce protocol, the Balke protocol is rather limited when one attempts to obtain appropriate exercise responses in a reasonable amount of time (8 to 10 minutes) in populations of children ranging from very unfit to highly fit, from 6 to 18 years of age, or from normal healthy to chronically ill children.

In general, the Balke protocol may be modified to tailor it to the subject's age and fitness level by adjusting the constant treadmill speed and by starting at a higher grade. The goal is to keep the exercise time between 8 and 10 minutes.

Cycle Protocols

James Protocol

The James protocol separates subjects into 3 specific exercise protocols consisting of 3 progressive 3-minute stages at predetermined work rates based on gender and body surface area. After completion of these 3 stages, work rate is increased by ~100 or 200 kilopounds-meter per minute (kpm/min) (18 or 36 W/min) until a maximal voluntary effort is reached. This protocol has some limitations when applied to small children or children with moderate to severe exercise intolerance in whom test duration may range between 4.5 and 7 minutes, thus providing limited data for analysis.

McMaster Protocol

The McMaster protocol separates subjects into 3 specific exercise protocols of 2-minute stages at predetermined work rates based on gender and height. The work rate increments in this protocol are linear, and the 2-minute duration of each stage seems to be long enough to achieve a pseudo-steady state for most physiological variables.

Strong Protocol

The Strong protocol separates subjects into 4 specific exercise protocols of 3-minute stages at work rates based on the subject's weight. The goal of the protocol is to determine physical working capacity at a heart rate of 170 beats per minute.

Progressive Incremental Cycle Ergometer Protocols

Included in this category are continuously incremental (ramp) protocols and protocols in which each stage lasts 1 minute. This kind of protocol is very efficient in providing exercise responses in a short amount of time, thus enabling acquisition of diagnostic data within 10 to 12 minutes.

Ideally, the slope of the ramp should be tailored to have subjects terminate the test within 10 minutes and is based on the child's body size and physical condition. A good estimate of this slope is S (W/min) = (predicted VO_2max − VO_2 unloaded)/92.5. However, in most cases a slope (i.e., work rate increment per minute) is selected on a case-by-case basis. An appropriate work rate increment for fit adolescents may be 20 to 25 W/min, whereas for unfit patients and young children it may be 10 W/min. For normal children, a work rate increment relative to body weight (3.5 W • min^{-1} • kg^{-1}) has been suggested.

Even though ramp protocols do not permit a steady state, the ramp-like change in work rate elicits submaximal responses that are equivalent to those derived from incremental protocols with stages lasting 2 to 3 minutes. However, to establish this correspondence and to interpret properly submaximal ramp responses, appropriate analysis is required. Consequently, because (1) most important exercise responses (e.g., cardiac output, oxygen uptake, minute ventilation, heart rate) during exercise in children have response times <1 minute; (2) work rate increment is typically <30 W/min in pediatric subjects; and (3) desired submaximal measurements (e.g., cardiac output) take <15 seconds to be completed, valid submaximal physiological responses to ramp changes in work rate can be obtained if appropriate and careful data analysis is performed.

Constant–Work-Rate Protocols

Submaximal constant–work-rate exercise tests of 5 to 10 minutes' duration are becoming more common in clinical exercise laboratories as an alternative protocol to maximal exercise tests. This is partly because submaximal exercise tests overcome some of the limitations of maximal exercise testing, which include (1) dependence on the patient's effort; (2) low sensitivity for measuring changes induced by therapeutic interventions; and (3) poor correlation with energy expenditure during activities of daily living, patient symptoms, and quality of life. The kinetic responses of oxygen uptake and/or heart rate at the onset of a brief bout of constant–work-rate exercise or during the recovery from the exercise bout can provide valuable information about the patient's ability to cope with the numerous changes in energy demand encountered in everyday life. A simple measurement, such as heart rate taken after a constant–work-rate exercise bout at an intensity that elicits a heart rate that corresponds to 70% to 85% of predicted maximum heart rate for the person's age, can have great predictive value. Indeed, a study conducted in a large adult population strongly suggests that the rate of heart rate recovery after submaximal exercise is associated with the person's risk of death. The longer it takes the heart rate to return to normal values, the greater the risk for death. When the observed patterns of physical activity in children are considered, submaximal exercise bouts of 1-minute duration at a work rate corresponding to ~90% of predicted maximum heart rate are more appropriate in a pediatric population. However, to date, reference values for healthy children and adolescents are not readily available for comparison.

Alternative Protocols

Six-Minute Walk Test

A 6-minute walk test may be more appropriate for assessing exercise tolerance in children with moderate to severe exercise limitation for whom traditional exercise testing may be too stressful. Guidelines established by the American Thoracic Society should be followed. Basically, the patient is encouraged to try to cover as much distance or as many laps on a measured course (often 30 m) as possible in 6 minutes. Patients using supplemental oxygen should perform the test with oxygen. Although many walk tests are done without monitoring, portable oximeters are available that enable continuous monitoring of both oxyhemoglobin saturation and heart rate without negligible additional weight. In the absence of portable equipment, it may be useful to monitor oxyhemoglobin saturation and heart rate before, during, and after the test. The patient is permitted to stop and rest but should resume walking if possible during the 6-minute period. Standard encouragement as outlined by the American Thoracic Society guidelines should be given. The total distance walked is the primary outcome. It has been suggested that distance walked should be multiplied by the patient's weight to reflect the work of walking. At least 2 practice tests performed on a separate day are advisable to minimize a learning effect and avoid fatigue. Because of the self-paced, submaximal nature of this test, the results may be more applicable than maximal exercise testing to everyday activities that the child may encounter. At this time, reference values for healthy children and adolescents are not readily available for comparison. However, the test is useful for following disease progression or measuring the response to medical interventions. The test is not as useful for healthier patients whose distance walked may be limited by leg length or height more than disease.

Exercise-Induced Bronchospasm Provocation

The exercise-induced bronchospasm (EIB) provocation allows for quantification of bronchial reactivity as measured by spirometry that is induced while a subject exercises for 5 to 8 minutes on a treadmill at an intensity of 80% of maximum capacity. The treadmill is preferable to cycle testing because it is more prone to induce bronchospasm. Additionally, the exercise room should be as cool (temperature 20 degrees C to 25 degrees C) and as dry as possible (relative humidity <50%) to elicit the best response. Both of these parameters should be recorded for each test. If feasible, some evidence indicates that having the child breathe very cold air (-20 degrees C) can increase the sensitivity of the exercise challenge. The exercise protocol should quickly increase the intensity to 80% of maximal capacity (using predicted heart rate maximum as a surrogate) within 2 minutes. If the intensity is not reached quickly, the likelihood of refractoriness to the development of bronchospasm will greatly increase. An incremental work rate used in many cardiopulmonary exercise tests (i.e., Bruce treadmill or Godfrey cycle protocols) is less likely to be effective in evaluating EIB because of its short duration of high ventilation and thus should be avoided in the evaluation of EIB. Additionally, use of prolonged warm-up periods may also induce refractoriness to EIB.

Exercise is preceded by baseline spirometry. Spirometry is repeated immediately after exercise and again at minutes 5, 10, and 15 of recovery. Most pulmonary function test nadirs occur within 5 to 10 minutes after exercise. If the child becomes symptomatic during or after testing even in the absence of a significant forced expiratory volume in 1 second (FEV_1) decline, a bronchodilator may need to be administered. Trained respiratory personnel should be available during and after exercise. Accepted criteria for a significant decline in FEV_1 after exercise are variable. Declines of 12% to 15% in FEV_1 are typically diagnostic.

Use of medications before testing should be considered in part on the basis of the clinical question being asked. Consultation with the child's primary care physician or asthma specialist will help to optimize the testing procedure.

Pharmacological Stress Protocols

Pharmacological stress testing is generally used when conventional exercise testing is unsuitable or impractical. These circumstances may include patients who are too young or are unable to perform exercise testing or in cases in which the motion of exercise may interfere with data collection. Such cases may include certain types of echocardiographic studies (see echocardiography protocols below).

Pharmacological stress testing is usually performed at the site where additional studies will occur, such as the echocardiography laboratory or the nuclear imaging suite. The patients require a peripheral intravenous line for the infusion of the pharmacological stress agent. Additional equipment will include appropriate infusion pumps, 12-lead ECG monitoring system, and blood pressure–monitoring equipment. Sedation is rarely needed but may be required for young patients or those patients with limited ability to cooperate with the testing protocol.

Two basic types of pharmacological agents exist: those that increase myocardial oxygen consumption and those that cause coronary vasodilatation. Dobutamine and isoproterenol are examples of the former and, to an extent, simulate the effects of exercise. Adenosine causes dilation of normal coronary artery segments, resulting in a shunting of myocardial blood flow away from diseased segments. Dipyridamole inhibits adenosine reuptake, resulting in the same physiology.

See original guideline document for specific dosing instructions of dobutamine, atropine, esmolol, dipyridamole, and adenosine.

The occurrence rate of significant adverse reactions to pharmacological stress in the pediatric population is unknown. However, reports in recent literature suggest that the rate is quite low. Nevertheless, care must be taken to ensure patient safety. Heart rate, rhythm, and ST-segment changes should be closely monitored throughout the study and in the immediate post-study period. Patients should be observed for any complaints or signs of chest pain, hypotension, or bronchospasm. Prompt termination of the infusion and reversal of the stress agent should be undertaken in any of these circumstances.

Echocardiography

Two basic types of exercise are used with echocardiography: treadmill and cycle ergometry (upright or supine). With treadmill and upright cycle testing, echocardiography is usually performed before exercise and immediately after exercise termination (within 60 to 90 seconds). In the case of supine cycle ergometry, echocardiography is performed before and during all stages of exercise (including peak). Oxygen consumption and cardiac output determinations can also be obtained. When pharmacological stress agents are used, imaging is performed as outlined in the section on pharmacological stress protocols.

Summary

The role of stress testing in the management of children and adolescents with both cardiovascular and noncardiovascular diagnoses and symptoms continues to increase. To perform these procedures properly, a complete understanding of exercise physiology in children is essential. Proper training of personnel and proper staffing of the pediatric exercise physiology laboratories are required to ensure the safety of patients and ensure that the desired testing information is accurately obtained. For these reasons, pediatric testing should remain an integral part of pediatric cardiology training.

CLINICAL ALGORITHM(S)

None provided

EVIDENCE SUPPORTING THE RECOMMENDATIONS

TYPE OF EVIDENCE SUPPORTING THE RECOMMENDATIONS

The type of evidence supporting the recommendations is not specifically stated.

BENEFITS/HARMS OF IMPLEMENTING THE GUIDELINE RECOMMENDATIONS

POTENTIAL BENEFITS

Appropriate and safe use of clinical stress testing in the pediatric population

POTENTIAL HARMS

The occurrence rate of significant adverse reactions to pharmacological stress in the pediatric population is unknown. However, reports in recent literature suggest that the rate is quite low. Nevertheless, care must be taken to ensure patient safety. Heart rate, rhythm, and ST-segment changes should be closely monitored throughout the study and in the immediate poststudy period. Patients should be observed for any complaints or signs of chest pain, hypotension, or bronchospasm. Prompt termination of the infusion and reversal of the stress agent should be undertaken in any of these circumstances.

CONTRAINDICATIONS

CONTRAINDICATIONS

Patients with acute myocardial or pericardial inflammatory disease or patients with severe outflow obstruction in whom surgical intervention is clearly indicated should generally not be tested.

IMPLEMENTATION OF THE GUIDELINE

DESCRIPTION OF IMPLEMENTATION STRATEGY

An implementation strategy was not provided.

INSTITUTE OF MEDICINE (IOM) NATIONAL HEALTHCARE QUALITY REPORT CATEGORIES

IOM CARE NEED

Living with Illness
Staying Healthy

IOM DOMAIN

Effectiveness
Patient-centeredness
Safety

IDENTIFYING INFORMATION AND AVAILABILITY

BIBLIOGRAPHIC SOURCE(S)

Paridon SM, Alpert BS, Boas SR, Cabrera ME, Caldarera LL, Daniels SR, Kimball TR, Knilans TK, Nixon PA, Rhodes J, Yetman AT, American Heart Association Council on Cardiovascular Disease in the Young. Clinical stress testing in the pediatric age group: a statement from the American Heart Association Council on Cardiovascular Disease in the Young, Committee on Atherosclerosis, Hypertension, and Obesity in Youth. Circulation 2006 Apr 18;113(15):1905-20. [75 references] PubMed

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FINANCIAL DISCLOSURES/CONFLICTS OF INTEREST

The American Heart Association makes every effort to avoid any actual or potential conflicts of interest that may arise as a result of an outside relationship or a personal, professional, or business interest of a member of the writing panel. Specifically, all members of the writing group are required to complete and submit a Disclosure Questionnaire showing all such relationships that might be perceived as real or potential conflicts of interest.

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*Modest.

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GUIDELINE STATUS

This is the current release of the guideline.

GUIDELINE AVAILABILITY

Electronic copies: Available from the American Heart Association Web site.

Print copies: Available from the American Heart Association, Public Information, 7272 Greenville Ave, Dallas, TX 75231-4596; Phone: 800-242-8721

AVAILABILITY OF COMPANION DOCUMENTS

None available

PATIENT RESOURCES

None available

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